

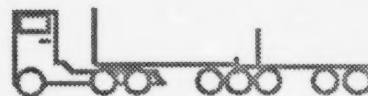


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Demonstration of Baseline Vehicle Performance: A-Train Double



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Demonstration of Baseline Vehicle Performance: A-Train Double

J.R. Billing
Head,
Commercial Vehicles Section

W. Mercer
Research Engineer

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Authors (name, title and/or organization): J.R. Billing, Head, Commercial Vehicles Section W. Mercer, Research Engineer			
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Abstract: An A-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations. The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface. This report presents detailed results of the tests and demonstrations.			
Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test			
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ABSTRACT

An A-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a base-line vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

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1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of an A-train double trailer combination baseline vehicle. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and two tandem-axle flatbed semitrailers with a single-axle A-type converter dolly. The combination is typical of equipment used in all regions of Canada, except the Atlantic provinces. The same combination was also tested concurrently as a C-train, using a B-type converter dolly [4].

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailers or dolly except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailers used were both manufactured by Fruehauf in Winnipeg and were model PB-F2-26-102-SF. Serial numbers were DXT2796-08 and DXT2796-06. Each trailer had a nominal length of 7.93 m (26 ft) and a nominal width of 2.44 m (96 in). Each had two axles spaced 1.24 m (49 in) apart and suspended from a Reyco 21B four-spring leaf suspension system with torque rods and equalizer arms. The spring centre spacing for each trailer was 0.96 m (38 in), and the track width was 2.44 m (96 in). The A-dolly comprised a standard A-dolly frame and a Reyco 21B leaf spring system with a torque rod. The A-dolly had a spring centre width of 0.98 m (38.5 in), and the track width was 2.44 m (96 in). The fifth-wheel-to-hitch distance was 2.14 m (7 ft). The combination had an overall length of 21.07 m (69.13 ft).

The trailers and dolly were fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 600 km (370 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 24 368 kg (53 610 lb). Concrete blocks were used to obtain a loaded weight of 47 699 kg (104 940 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	5 082	11 180	5 127	11 280
2	3 845	8 460	5 327	11 720
3	3 027	6 660	5 486	12 070
4	2 205	4 850	5 250	11 550
5	2 277	5 010	6 882	15 140
6	3 323	7 310	7 400	16 280
7	2 950	6 490	6 936	15 260
8	1 659	3 650	5 291	11 640
Total	24 368	53 610	47 699	104 940

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was not closely attained. Both trailers were loaded in the same fashion. The legal gross weight of the vehicle tested varies between 52 800 and 61 600 kg (116 160 and 135 520 lb), depending on the province.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.37 m (14.7 in) below the top of the floor. The centre of gravity height was estimated as 0.20 m (8 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

- 1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
- 2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailers, and safety cable attachments were installed on the dolly.
- 3/ Outriggers were installed on the trailers.
- 4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
- 5/ New tires were installed, and pressures were set.
- 6/ Other fittings necessary for testing were installed.
- 7/ Concrete blocks were located on the trailer beds to achieve specified axle loads.
- 8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
- 9/ The MTC tractor was coupled to the trailers.
- 10/ The combination vehicle was weighed, empty and loaded.
- 11/ A functional test of the on-board electronics was conducted.
- 12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
- 13/ Tires were run a nominal distance of 160 km (100 mi).
- 14/ Articulation angle between the tractor and lead trailer was calibrated.
- 15/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailers and dolly for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailers were mounted in boxes placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition.

Table 2/ Instrumentation Installed

No Measurement	Instrument	Full Scale
1 Tractor steer angle	Spectrol 139 potentiometer	25.02°
2 Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3 Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4 Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5 Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6 Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7 Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8 Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9 Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10 Tractor treadle valve pressure	Celeco PLC-200G	100 psi
11 Tractor brake pressure, axle 2 Left	Celeco PLC-200G	99.80 psi
12 Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13 Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14 Trailer 1 articulation angle	Celeco pull cord DV-301-150	18.844°
15 Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16 Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17 Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18 Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19 Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20 Brake pressure, axle 4 right	Celeco PLC-200G	104.96 psi
21 Brake pressure, axle 5 right	Celeco PLC-200G	101.06 psi
22 Brake pressure, axle 6 right	Celeco PLC-200G	102.07 psi
23 Brake pressure, axle 7 right	Celeco PLC-200G	101.93 psi
24 Brake pressure, axle 8 right	Celeco PLC-200G	106.79 psi
25 Spare		
26 Spare		
27 Trailer 2 articulation angle	Spectrol 8409 potentiometer	26.511°
28 Trailer 2 lateral acceleration	Columbia SA-107 accelerometer	0.980 g
29 Trailer 2 roll angle	Humphrey VM02-0128-1 vertical gyro	8.91°
30 Trailer 2 outrigger touchdown	Strain gauge bridge	1.0 V

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

This test was performed with a wet surface. The results are shown on Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, it was found that the vehicle offtracked 1.45 m (4.76 ft).

Table 3/ Offtracking

Axle No.	Track Width	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.57	27.65	0.08	27.61	27.56	-0.18
2	2.37	27.22	27.35	0.13	27.29	27.21	-0.29
3	2.37	27.24	27.35	0.09	27.29	27.21	-0.29
4	2.37	26.63	26.77	0.14	26.70	26.64	-0.23
5	2.37	26.62	26.75	0.13	26.69	26.64	-0.19
6	2.37	26.58	26.69	0.12	26.64	26.59	-0.19
7	2.37	26.02	26.12	0.10	26.07	26.02	-0.19
8	2.37	26.01	26.08	0.07	26.05	26.02	-0.12

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft)

radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn. The maximum excursion out of lane was only 0.4 m (1.3 ft). It was out of the exit lane for a distance of 7.5 m (24.6 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was 1.85 m (6.1 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle easily made it through the channel.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. The dolly was not equipped with a booster relay valve to speed the signal. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi). Pressure transducers were installed at all trailer and dolly axles.

The SAE J982a style test was performed for the full double combination. The results of this test, presented in Table 4, are the average of several tests each with a time resolution of 0.02 s. The application times of this test were typical of those obtained from tests on other double

combinations [13]. The release times are considered very long, especially for the lead trailer. A typical time history response of application and release for the double is presented in Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.04	0.19	98.8
Axle 2	0.39	0.65	98.4
Axle 4	0.57	3.02	95.1
Axle 5	0.56	3.04	95.0
Axle 6	0.81	2.26	94.8
Axle 7	0.79	2.31	92.0
Axle 8	0.77	2.28	93.7

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit. Yaw response of all vehicle units are presented in Figure 4.5.1 as a function of brake application pressure.

The time history of a typical run that resulted in loss of control is shown in Figure 11. An average brake application of about 186 kPa (27 psi) over the entire stop caused all braked wheels, except axles 5 and 7 on the left-hand side, to lock. The tractor and lead trailer

remained straight, but the inertia of the rear trailer was sufficient to jackknife the dolly to the right. The rear trailer tandem axle remained more or less in line, but as a consequence of the dolly jackknife, the rear trailer headed to the right. While the entire vehicle actually remained within the lane, the dolly was unstable by jackknife, and this cannot be considered an acceptable stop.

A summary of peak vehicle responses from the runs is shown in Figure 12 as a function of average treadle valve over the entire stop. The limit of surface adhesion of about 0.15 g was reached by a brake application of 173 kPa (25 psi), when most braked wheels were locking. The dolly was clearly getting pushed in all stops. The vehicle, therefore, was sensitive to hard breaking.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 22.5 m (73.8 ft) for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration amplitude of all vehicle units increased with speed up to approximately 63 km/h, at which point the tractor and first trailer tended to level off. The heading angle of the tractor and first trailer decreased, indicating minor in-lane sliding. The heading angles of the rear trailer increased slightly with speed. The rear trailer tended to swing on return to the original lane. The driver commented that the vehicle tended to "push" at higher speeds, and his steer pattern tended to change at higher speeds, indicating tractor understeer/oversteer at different points in the course. The driver was able to make this manoeuvre at 63 km/h, the maximum speed considered safe for such a manoeuvre at the test site. While the vehicle manoeuvred neatly through the second gate, the dolly appeared on the verge of jackknife, and this would have precipitated a severe and probably catastrophic trailer swing. A typical run at 63 km/h

is shown in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63 and 94 km/h, with steer input periods between about 2 and 5 s. Weather conditions precluded runs at 84 km/h.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration for the two trailers is presented in Figure 15, as a function of tractor steer input period for the two test speeds. Each gain is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15 that rearward amplification increases with speed. It also increases rearward by trailer. Finally, it is also somewhat sensitive to steer period, reaching its highest value for the rear trailer of about 1.80 at 94 km/h around 2 s. This result shows that, at highway speed, the A-train double is a highly responsive vehicle. The reason for this is that its inherent stability is rather low. Stability and response of mechanical systems have an inverse relationship. High stability means low response to input and vice versa. Figure 16 shows the vehicle response from a typical run with a steer period of about 1.64 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. The test was not conducted for this vehicle because poor weather interfered with the test schedule. Exactly the same test was, however, conducted in an earlier test program with a similar vehicle [14]. A series of runs was made where the driver made a lane-change manoeuvre, which is considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with those described in the preceding section.

From previous data it was found that lateral acceleration gain of the rear trailer increased from 1.2 at 75 km/h to 1.8 at 85 km/h, and roll gain increased from 3 at 74 km/h to 7 at about 75 to 80 km/h. The vehicle tended to slide as well as roll. Yaw overshoot of the rear trailer was quite high at the ultimate speed of 83 km/h, when the rear trailer swung out of lane to the left and rolled violently to outrigger touchdown.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was highly responsive, so the slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in rear trailer sway that was perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 1.74 g/° of RMS steer input. RMS sway of the rear of the rear trailer relative to the tractor steer axle was 428 mm/° (16.9 in/°) of RMS steer input. The articulation angles were very small, so this latter value is regarded as suspect.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and to examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 17 as average steady-state values. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. At the limiting speed of

55 km/h, a lateral acceleration of 0.53 g, the rear trailer rolled over and the dolly slid out from the circular trajectory, as shown in Figures 18 and 19. As Figure 17 shows, roll angles increased with speed. The values at the point of rollover are omitted because there was insufficient steady-state data to record a proper average. Average steady-state articulation angles are also shown in Figure 17. These decreased modestly with increase in lateral acceleration, and as a consequence, the offtracking decreased. The lateral force experienced by the tractor fifth wheel is shown in Figure 17, as a function of tractor lateral acceleration. This shows a gradient of about 49 kN/g (11 000 lb/g).

A tilt test was conducted on this vehicle as part of a separate test program [15]. The vehicle is shown in the tilt table in Figure 20. The high-side wheels of the rear trailer lifted at a tilt angle of 29.1° after all corrections were made, which corresponds to a lateral acceleration of 0.56 g. This is in quite good agreement with the rear trailer's lateral acceleration at outrigger touchdown of 0.52 g. A full discussion of the tilt test is presented elsewhere [15].

The trailer centre of gravity was about 1.75 m (70 in) from the ground. Van and tanker-type trailers can have centres of gravity up to about 2.5 m (100 in) from the ground, which would reduce the rollover threshold from 0.53 g in this test to about 0.30 g [16].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, in both empty and loaded conditions. In both conditions, the centre of gravity was somewhat lower than normal, particularly for the loaded condition, because of the under-slung outriggers.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results, except for centre of gravity height, which has been mentioned already where it may have affected the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. The short trailer wheelbase made it easy to manoeuvre in both low-speed turns and dynamic tests, as the trailer imposed rather modest forces on the tractor. While the vehicle performed very well from the point of view of the driver to the point where loss of control occurred, at that point the consequences appear more severe than with the comparable B- or C-train. The driver can feel the approach to the stability threshold with these vehicles, whereas with the A-train, there is no feel for the rear trailer. This provides a definite difference in the test situation, where there is a steady approach to the stability threshold.

However, on the highway in an emergency accident avoidance situation, the driver has one chance to make the proper response. Many accidents are avoided by defensive driving. Others, unfortunately are unavoidable. Since loss-of-control-type accidents are relatively infrequent for heavy trucks, it may be questionable whether many, if any, are provably avoidable with a more stable vehicle configuration. In an A-train the driver emergency response may result in tractor or dolly jackknife on a low-friction surface, or rear trailer swing or rollover on a high-friction surface. Except for tractor jackknife, the driver would retain control of the tractor. However, with the B- or C-train, the rollover situation

would result in rollover of the entire vehicle. This might be more hazardous to other road users than rear trailer rollover of the A-train, and, certainly, is more likely to cause serious or fatal injury to the driver. If it is accepted that there are very few true emergency situations when vehicle configuration might affect the outcome -- accident or no accident -- then there is little argument against the A-train. Indeed, as an easier vehicle to manoeuvre, and excepting trailer sway, it might be argued that it reduces hazard because of a lower driver workload. In another area of safety, however, there are also few accidents that are clearly due to poor brakes, though it is well known that heavy truck brake standards and usage are much less than ideal. Yet it remains an article of faith with safety professionals that no effort should be spared to improve brake systems. Following similar logic, then, the B- or C-train should always be preferred to the A-train, not only for its margin of stability but more particularly for the feedback the entire vehicle provides the driver. If the driver can feel some reduction in vehicle stability, particularly on a low-friction surface, then the responsible professional driver will drive more defensively, and potential accident situations will be avoided. However, doubles are typically driven by the more experienced drivers, so it may be questioned whether additional caution would be realistic. This topic has not been exhaustively researched, and further speculation is possible. For want of more information, however, there is no question at this time that the laws of physics should prevail, and the more stable vehicle configurations -- the B- and C-trains -- should be preferred to the A-train, to the greatest extent possible.

6/ CONCLUSIONS

An A-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The short trailers and articulation points of this vehicle clearly contributed to the modest space required to make turns.

The air brake system was typical of A-train doubles without a booster relay valve.

The vehicle was quite responsive, with a rearward amplification of lateral acceleration of about 1.80. The lateral/directional stability of the vehicle, therefore, was poor, both empty on a low-friction surface and loaded on a high-friction surface. Stability was clearly deteriorating at the highway speed limit of 100 km/h.

The A-train double configuration is considered undesirable because of its low stability at highway speeds. The C-train configuration is preferable from this point of view, as demonstrated in a parallel series of tests. However, the A-train is an easier vehicle to drive in some respects than the C-train.

The roll stability was relatively high because the centre of gravity of the trailer was very low. A higher centre of gravity would have significantly reduced the roll threshold.

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Figure 1/ A-Train Double, View of Vehicle

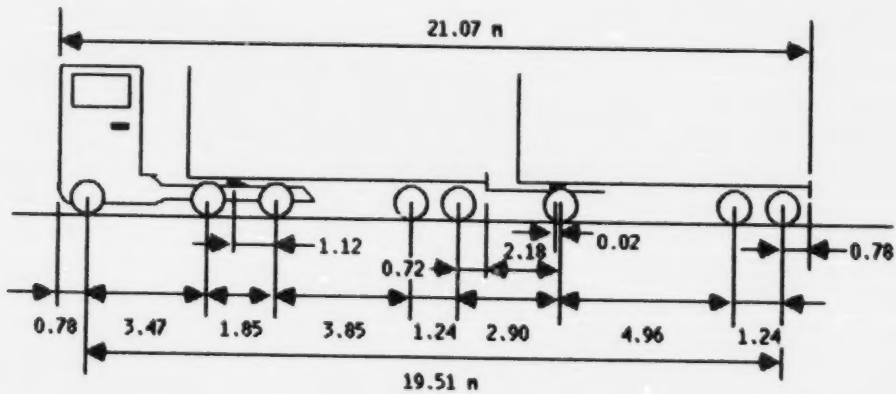


Figure 2/ A-Train Double, Vehicle Dimensions



**Figure 3/ A-Train Double,
Clockwise Offtracking**

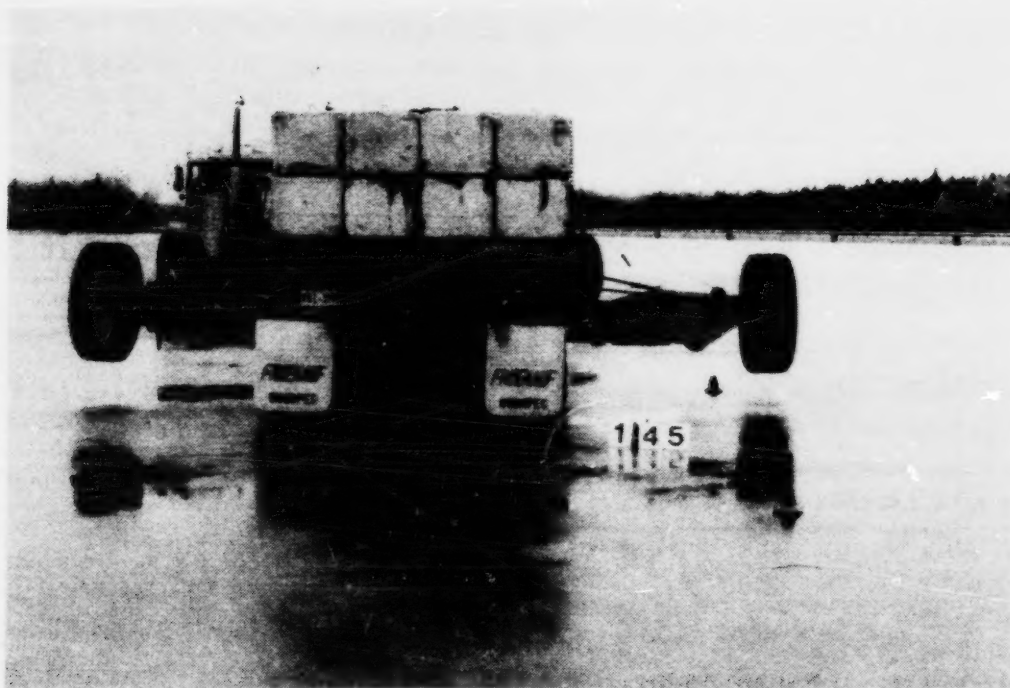


**Figure 4/ A-Train Double,
Counter-Clockwise Final Offtracking**

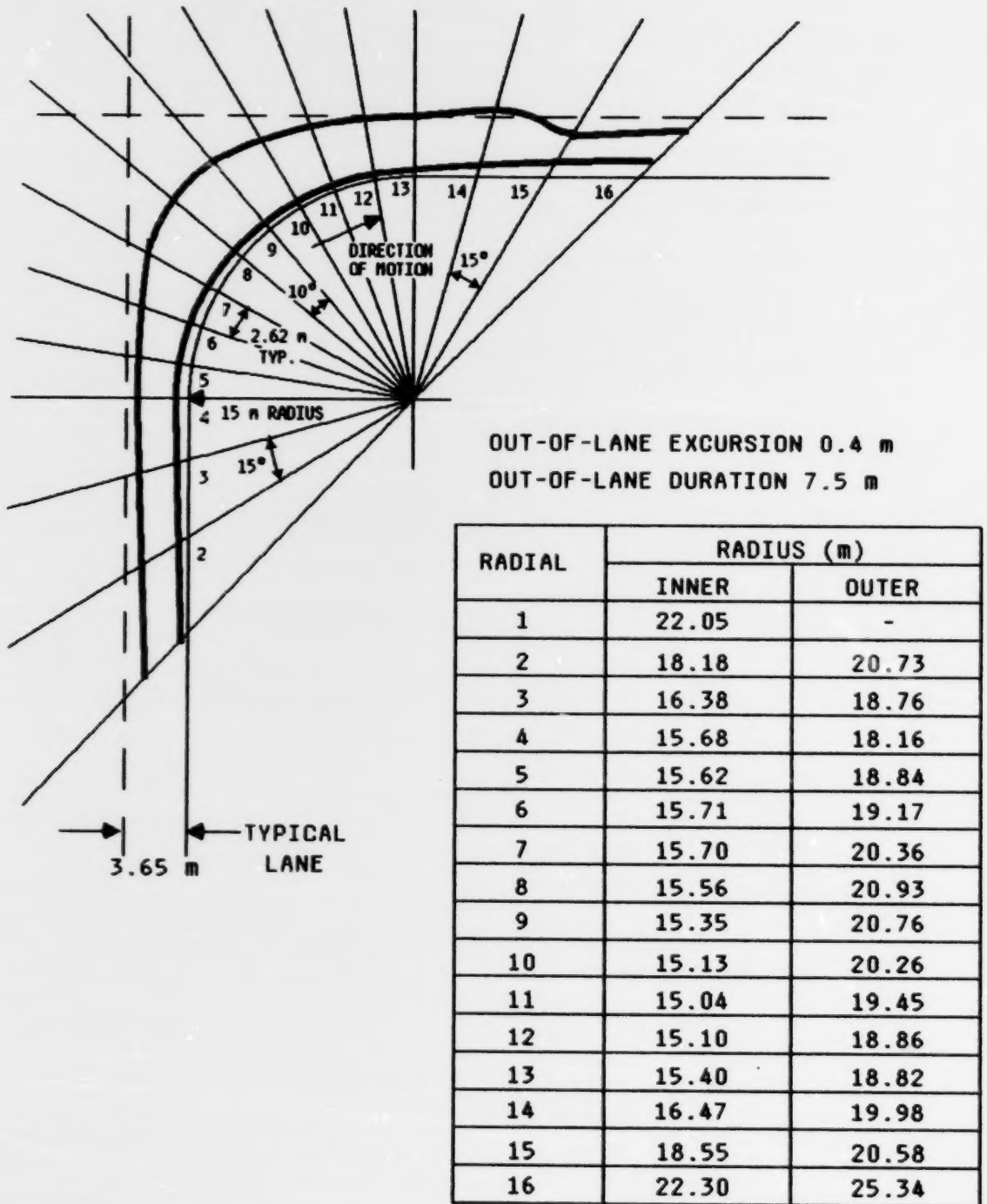


Figure 5/ A-Train Double, Right-Hand Turn Swept Path

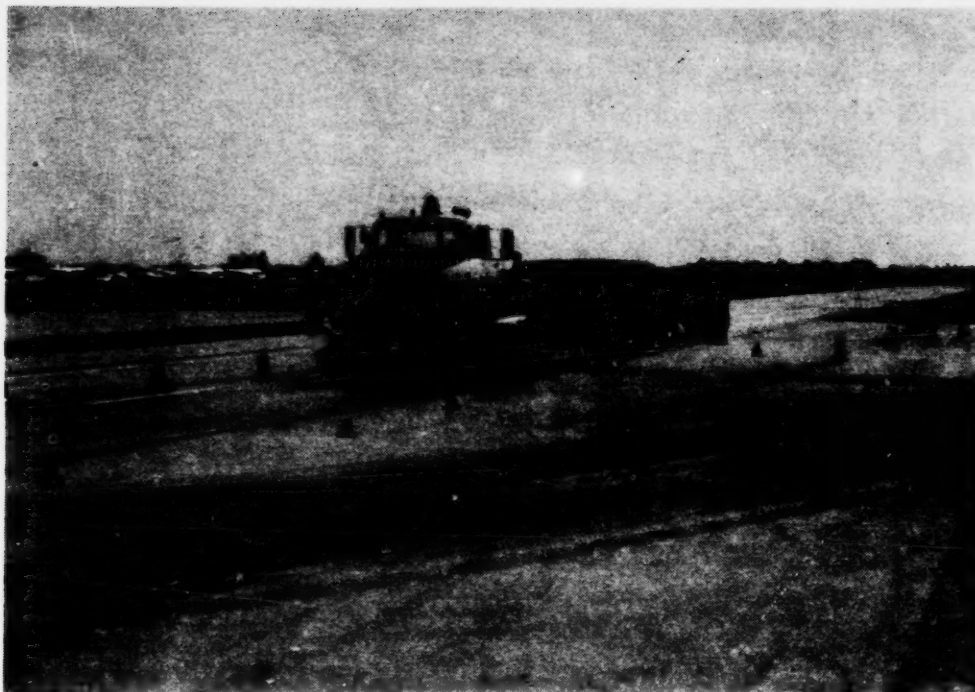
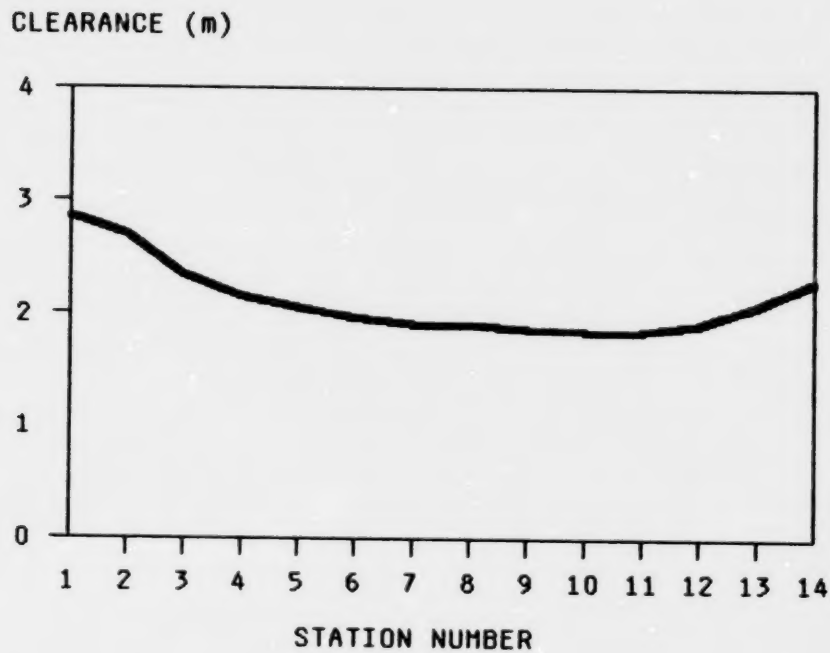


Figure 6/ A-Train Double, Right-Hand Turn



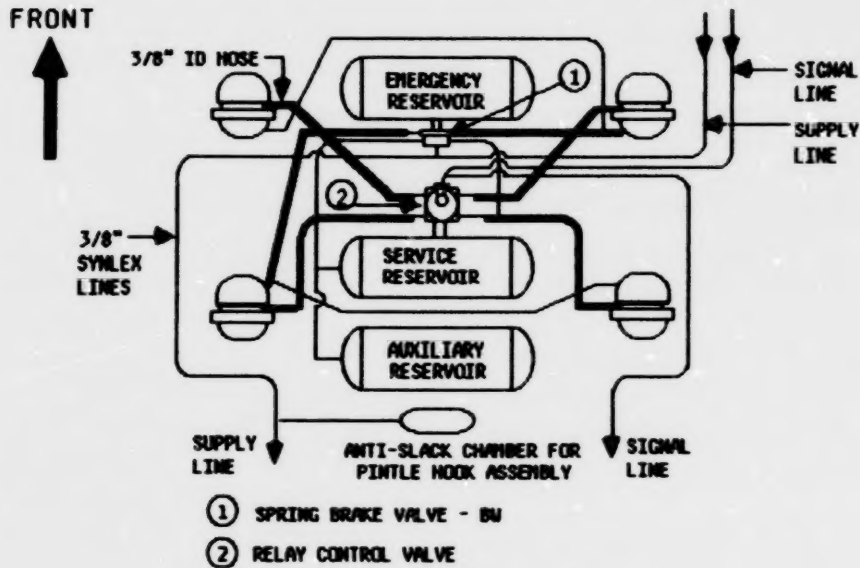
Figure 7/ A-Train Double, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.85
2	2.69
3	2.34
4	2.15
5	2.05
6	1.95
7	1.92
8	1.90
9	1.86
10	1.85 *(LOW)
11	1.85 *(LOW)
12	1.92
13	2.08
14	2.28

Figure 8/ A-Train Double,
Channelized Right-Turn
Clearance from Inner Curb

DOUBLE TRAILER (LEAD AND PUP)



A-DOLLY

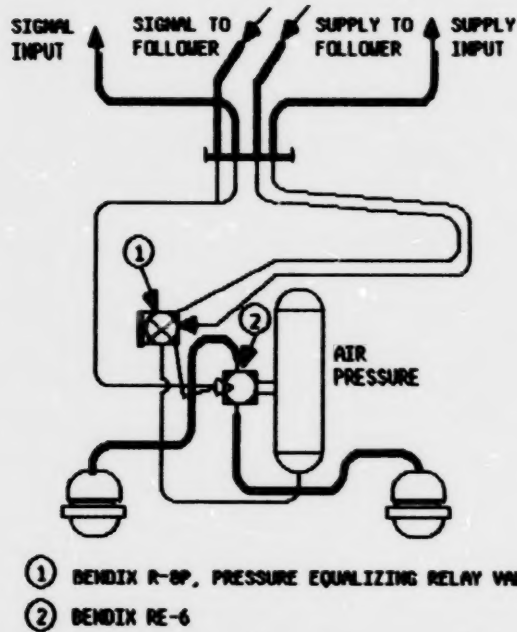


Figure 9/ A-Train Double Trailers and Dolly, Air Brake System Schematic

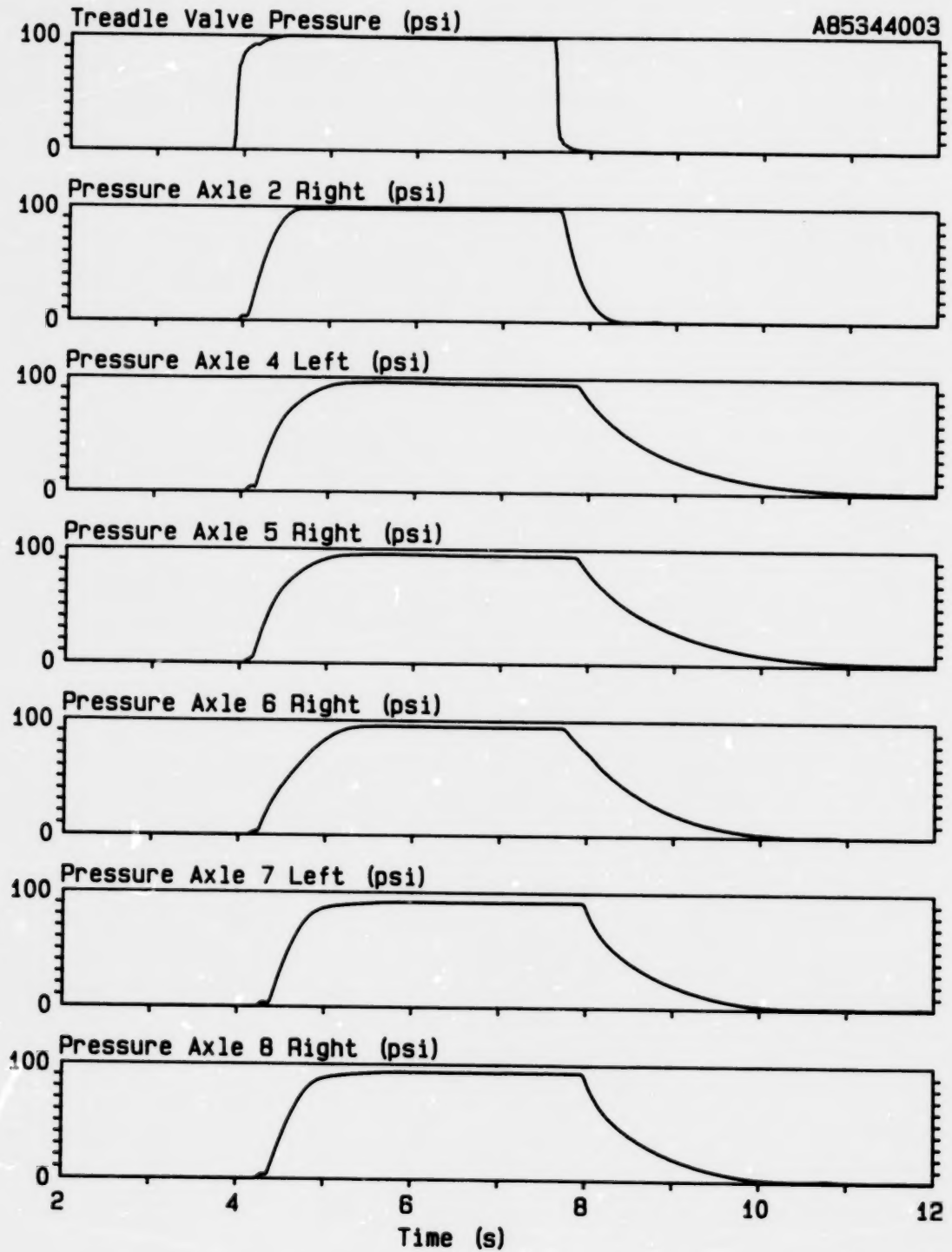


Figure 10/ A-Train Double,
Air Brake Application and Release

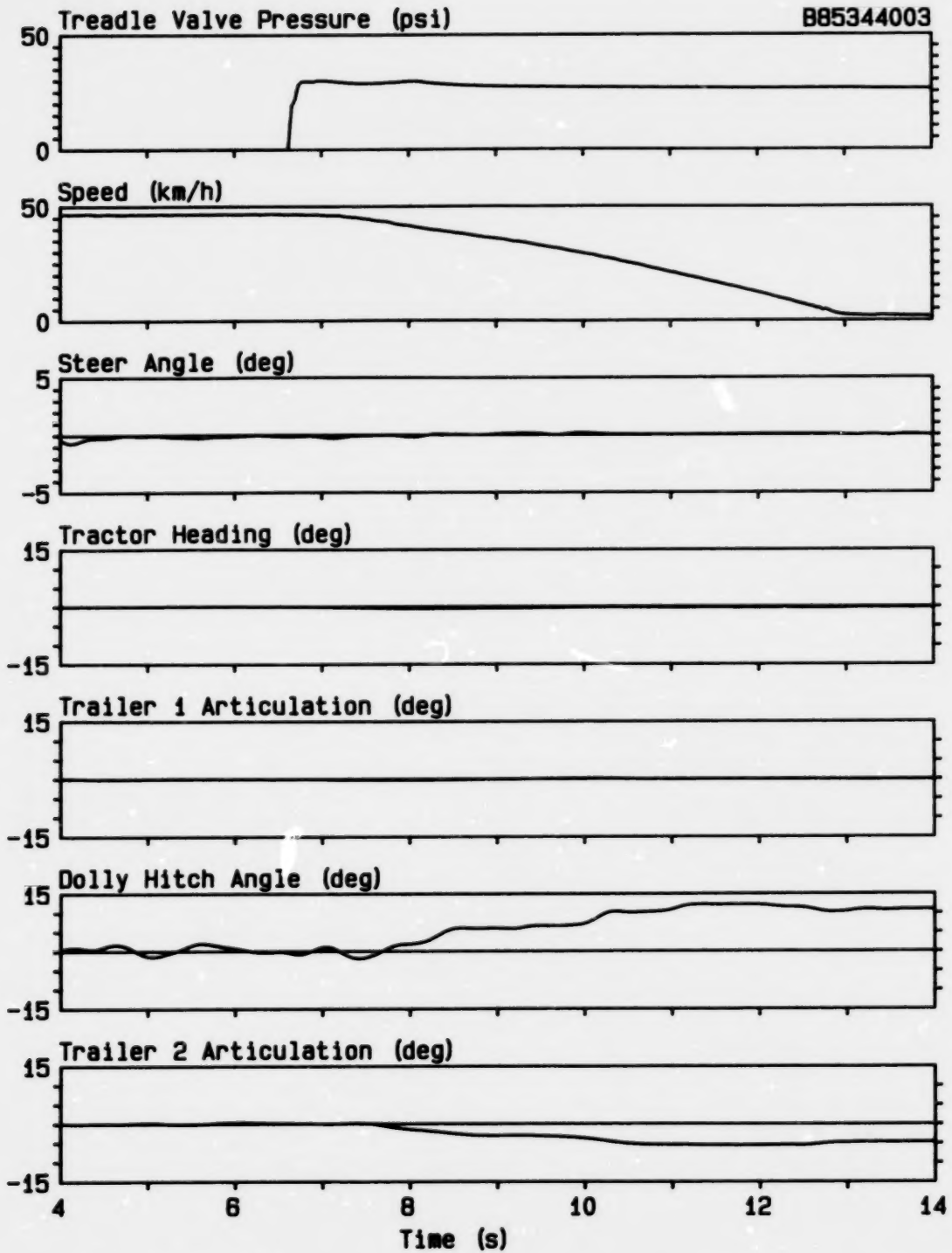


Figure 11/ A-Train Double,
Vehicle Response to Straight-Line Braking

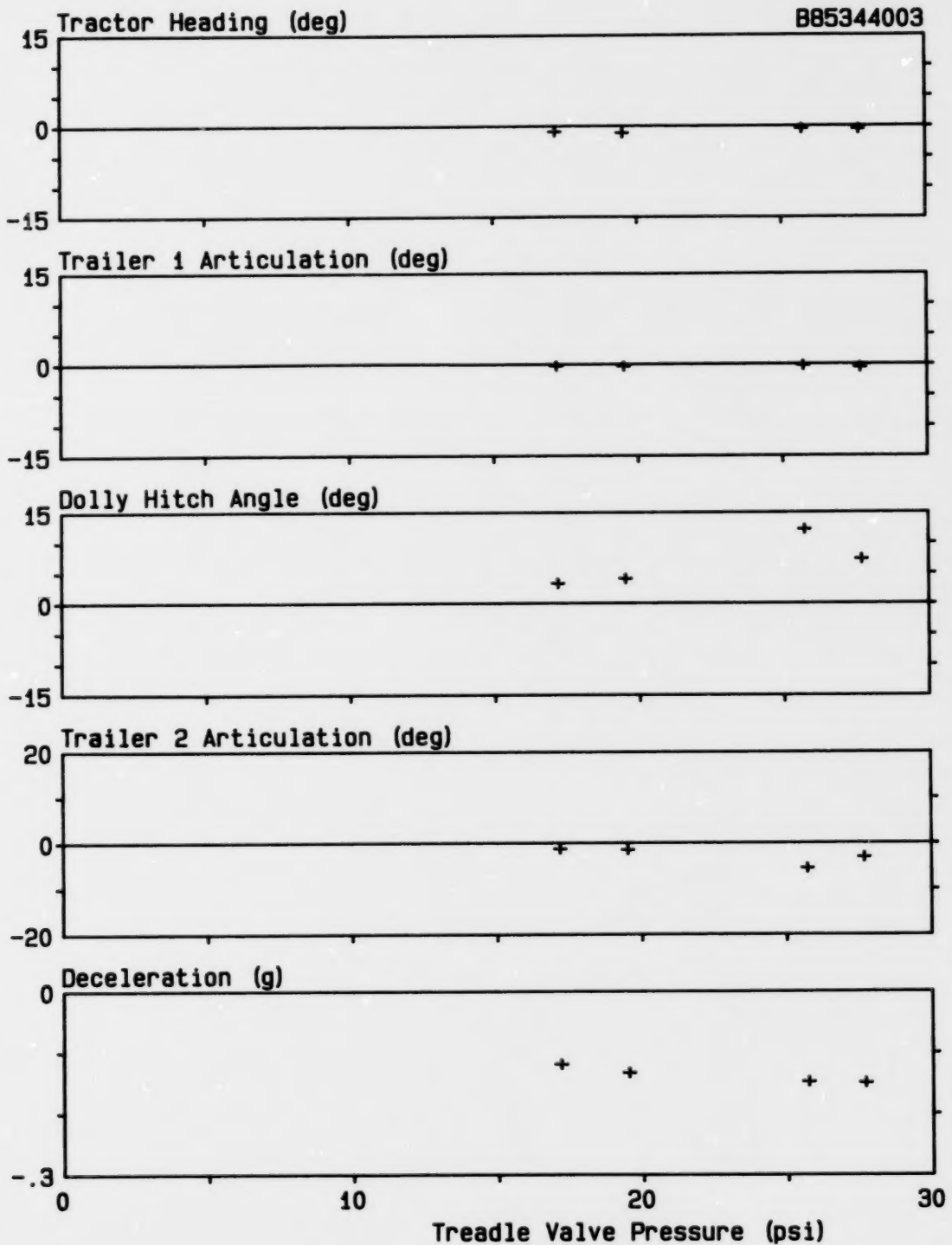


Figure 12/ A-Train Double, Straight-Line Braking
Responses vs Treadle Valve Pressure

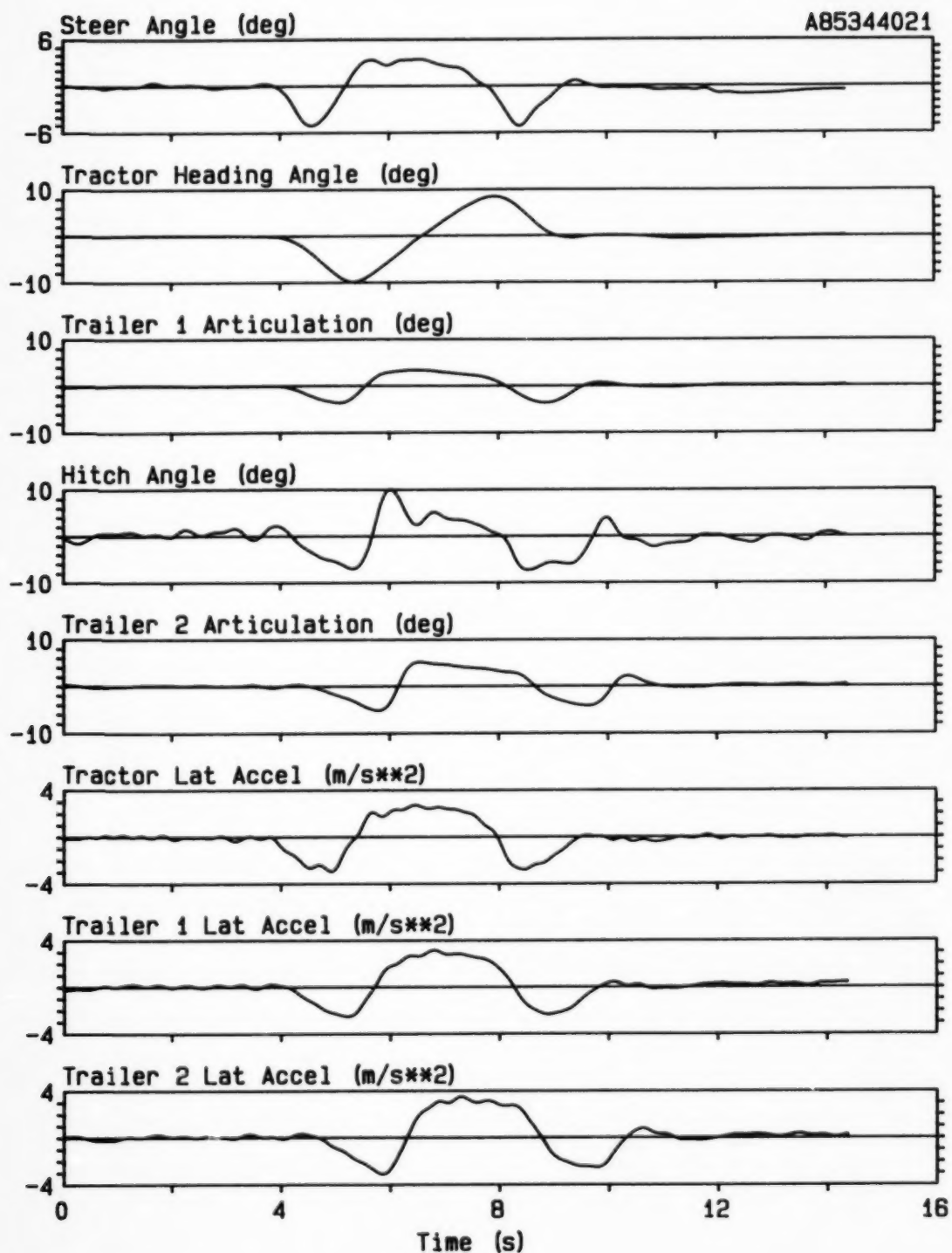


Figure 13/ A-Train Double, Evasive Manoeuvre,
Vehicle Response at 63 km/h

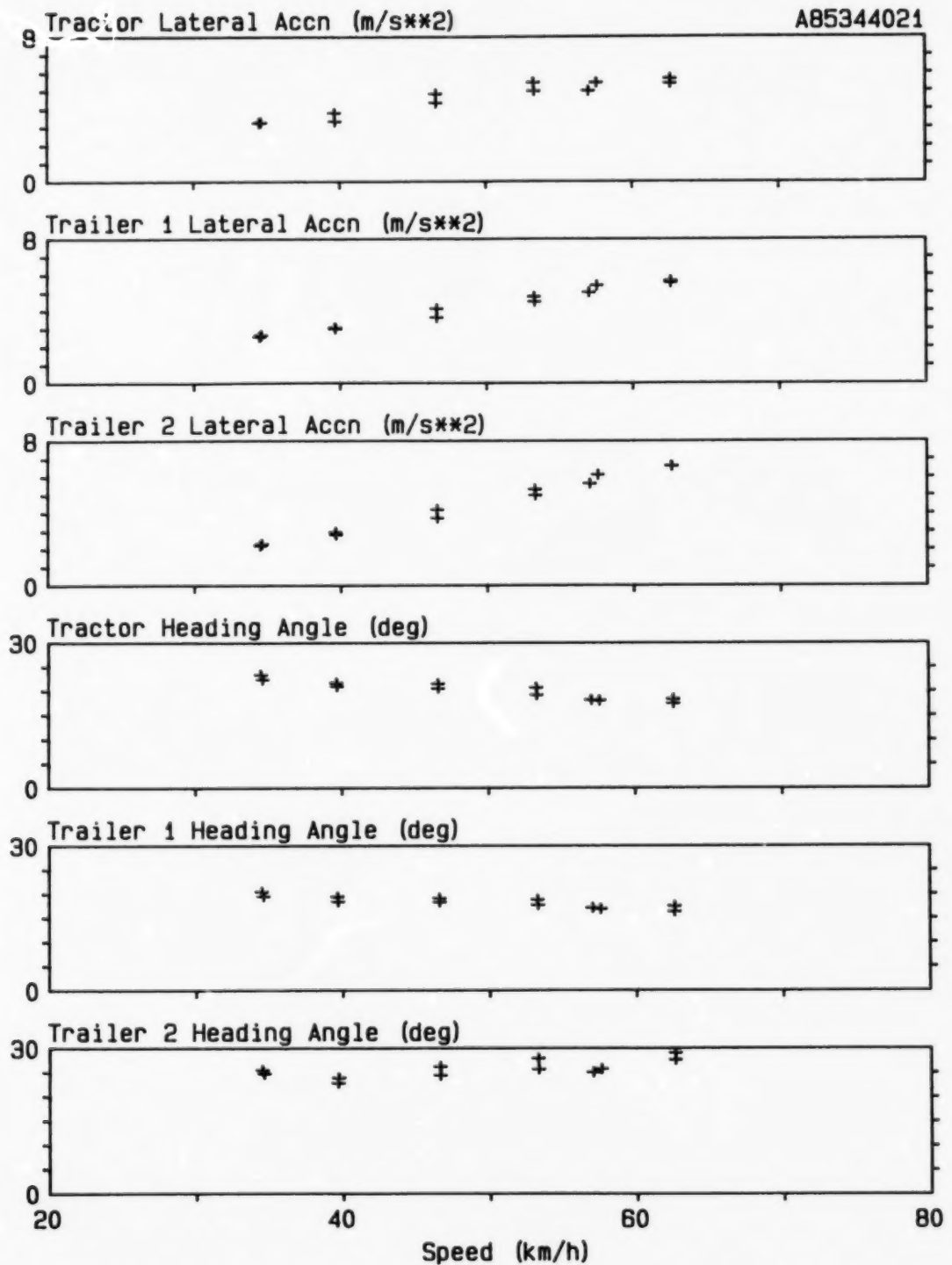


Figure 14/ A-Train Double, Evasive Manoeuvre,
Peak-to-Peak Responses vs Speed

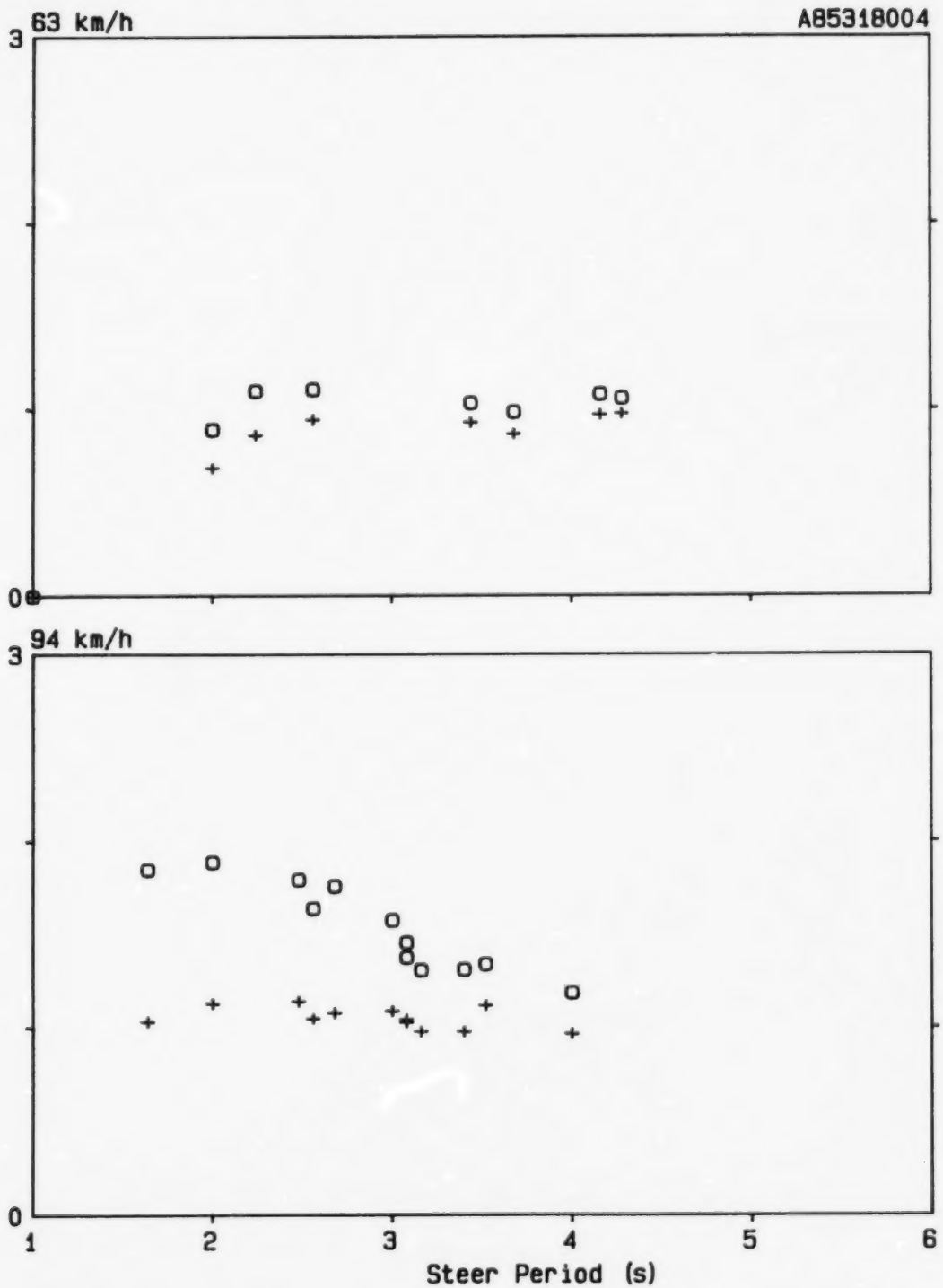


Figure 15/ A-Train Double,
Rearward Amplification vs Steer Period

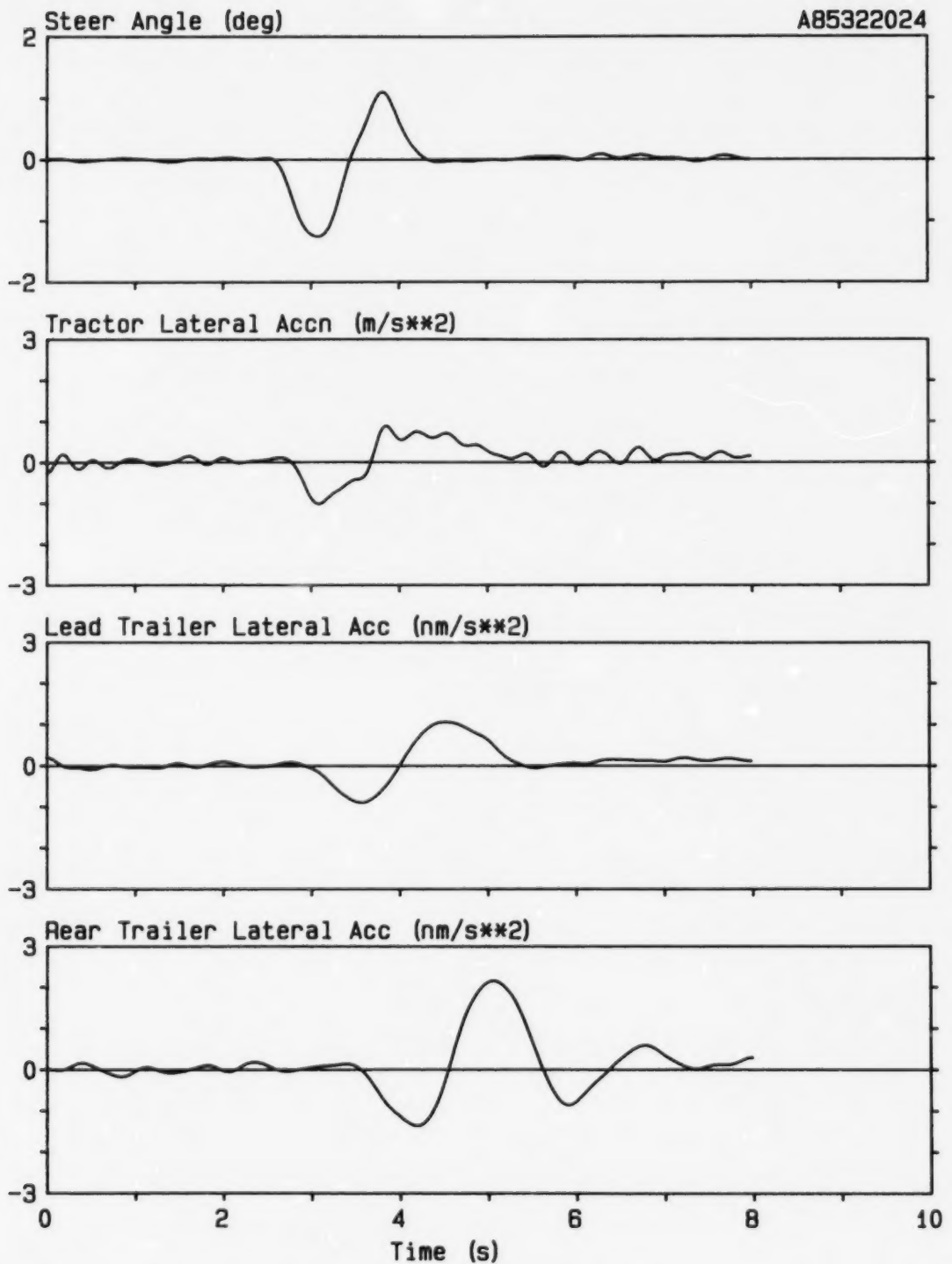


Figure 16/ A-Train Double, Sinusoidal Steer,
Vehicle Responses at 94 km/h

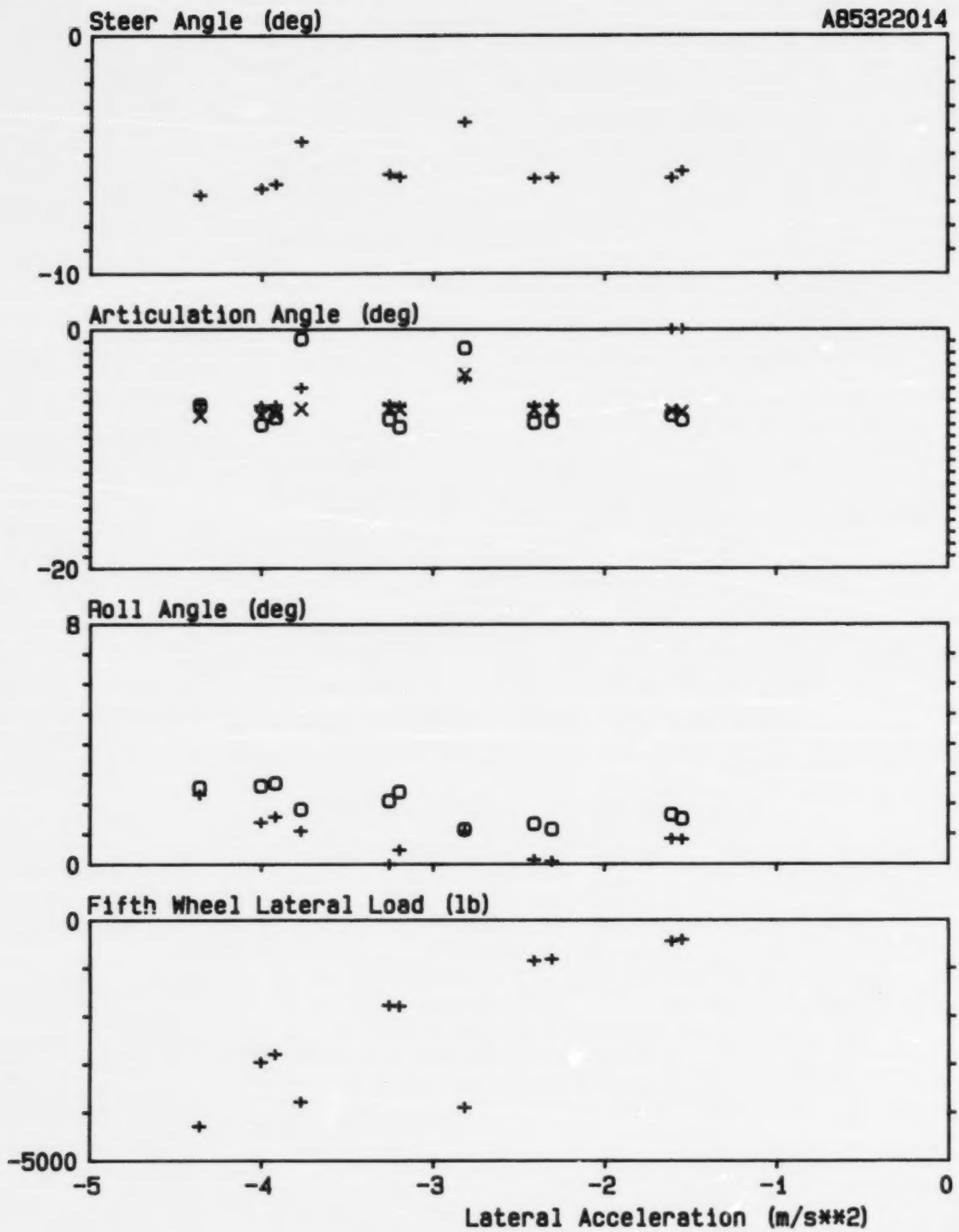


Figure 17/ A-Train Double, Steady Circular Turn,
Vehicle Responses vs Tractor Lateral Acceleration

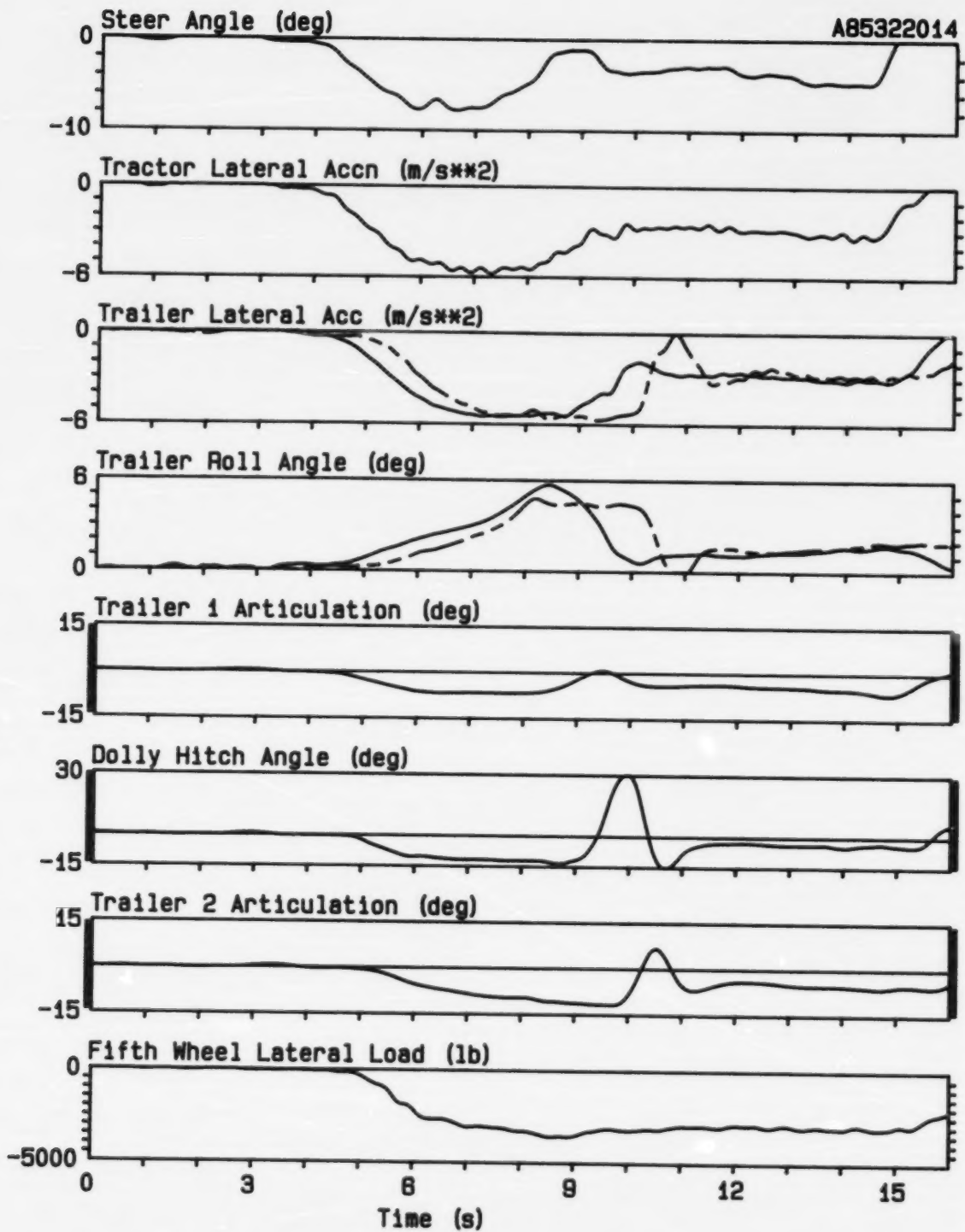


Figure 18/ A-Train Double, Steady Circular Turn,
Vehicle Responses at 82 km/h



Figure 19/ A-Train Double Making Steady Circular Turn

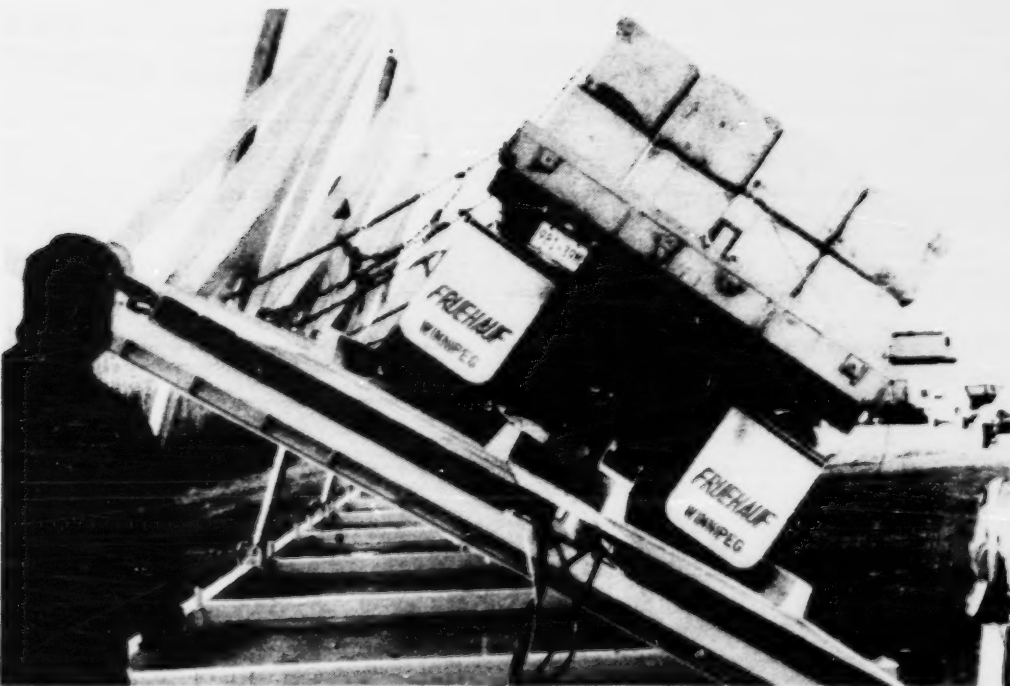


Figure 20/ A-Train Double Vehicle on Tilt Table